SOLAR ENERGY

GCEP

Global Climate & Energy Project
STANFORD UNIVERSITY

Upconverting Electrodes for Improved Solar Energy Conversion

Investigators

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Objective

Only a small portion of the solar spectrum can be used by photovoltaic and photocatalytic devices, which rely on photon absorption. The results will enable a scalable, single-junction solar cell capable of utilizing nearly the entire solar spectrum, without the need for solar concentration. The proposed technology is aimed at the introduction of cheap, highly efficient solar cells which would eliminate the largest obstacle to widespread solar-energy deployment – namely, the high cost per unit energy produced, which must compete with a cost of $0.06/kW·hr for grid power. The project focus will be the use of solution-dispersed materials that will enable the use of low-cost and highly scalable manufacturing technologies such as spray coating.

Background

Current photovoltaic and photocatalytic technologies can harvest only a small fraction of energy, since they are generally unable to utilize photons with energies below the cell bandgap – the amount of energy a photon needs to free an electron from its bond. These transmission losses severely limit the maximum photovoltaic efficiency possible with a single junction device. For example, an ideal single-junction solar cell with a bandgap of 1.7 eV wastes approximately 49% of the sun's power. And transmission losses severely limit the maximum photovoltaic efficiency possible with a single-junction device.

In recent years, considerable effort has been given to developing renewable energy technologies that reduce the spectral mismatch between solar cells and the solar spectrum. Rather than adapting the active semiconducting layer of a solar cell to better utilize sub-bandgap light, an upconverter can be used to reduce transmission losses. Placed behind a solar cell, the upconverter transforms low-energy photons to higher-energy photons that can then be absorbed by the solar cell and contribute to photocurrent. Upconversion has been observed in many materials systems, including lanthanoid ions, transition metal ions, metal-ligand complexes and semiconducting quantum dots. Such materials have been used for optical communications, photonic devices and *in vivo* bioimaging.

Approach

Figure 1 illustrates a schematic of the upconverting solar cell design. An upconverting electrode is placed behind the active semiconducting region of a cell to collect transmitted photons. The upconverter transforms the energies of these transmitted photons to energies that can be absorbed by the solar cell. The electrode consists of synthesized nanostructures, including upconverter-doped dielectric nanoparticles and silver nanowires, which can be deposited over large areas by spray coating. While the upconverter-doped nanoparticles improve absorption of sunlight, the silver nanowires provide direct electrical contact to the cell, enabling carrier extraction.

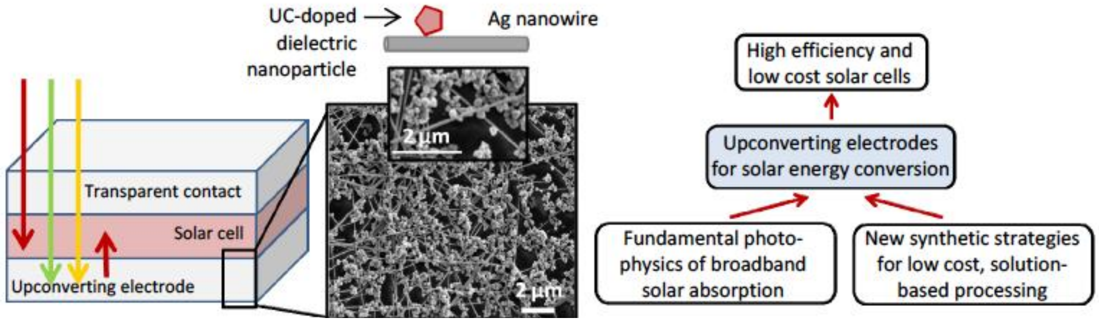

Figure 1: Schematic of a photovoltaic cell with the proposed upconverting electrode made of silver nanowires decorated with upconverter-doped nanoparticles. The scanning electron micrograph shows spray-coated electrodes of silver nanowires with zinc oxide nanoparticles. The right panel illustrates the specific aims of this research.

The cell design is characterized by three innovative but essential parameters: (1) decoupled optical and electrical parameters, (2) enhanced photon absorption above and below the bandgap, and (3) excellent electrical conductivity**.**

Analytic and computational models will be used to determine the photovoltaic efficiency enhancements that can be achieved with this upconverter electrode. There will be three broad categories of research: (1) fundamental photophysics of broadband solar absorption, (2) new synthetic strategies for low-cost, solution-based processing, and (3) photovoltaic device fabrication and characterization. Full-field simulations will be used to model the nanophotonic properties of upconverting nanoparticles near plasmonic nanowires. Synthetic attention will be given to controlling the shape, size and crystalline phase of upconverter-doped nanoparticles. Experiments will explore the electrical and optical properties of these upconverting electrodes, including measurements of upconversion photoluminescence efficiencies, upconverter radiative lifetimes and electrical transport through nanoparticle-decorated nanowires. The proposal will culminate in photovoltaic cell fabrication and characterization using the proposed upconverting electrodes.

Figure 2 shows how the three-level upconverting system will be mathematically modeled.

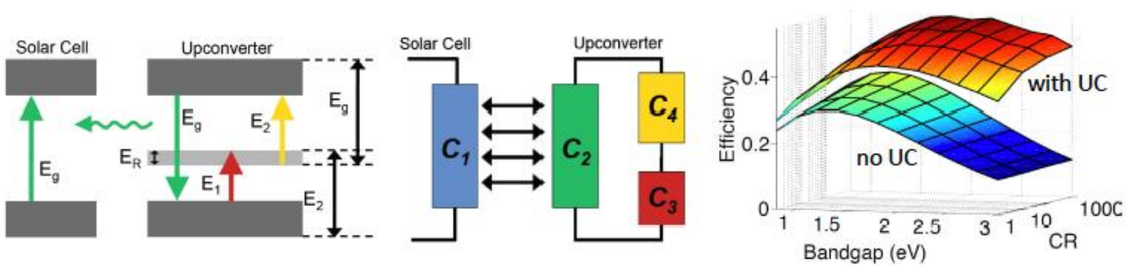

Figure 2: The upconverter is assumed to optically interact with the cell while remaining electronically isolated. E_g is the bandgap energy. An intermediate level of energy $E_1<E_g$ lies above the valence band edge and is separated by E_2. The cell-upconverter system will be mathematically modeled as four individual solar cells: the main cell (C_1) and the three series-connect cells that form the upconverter (C_2, C_3, C_4).

References

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